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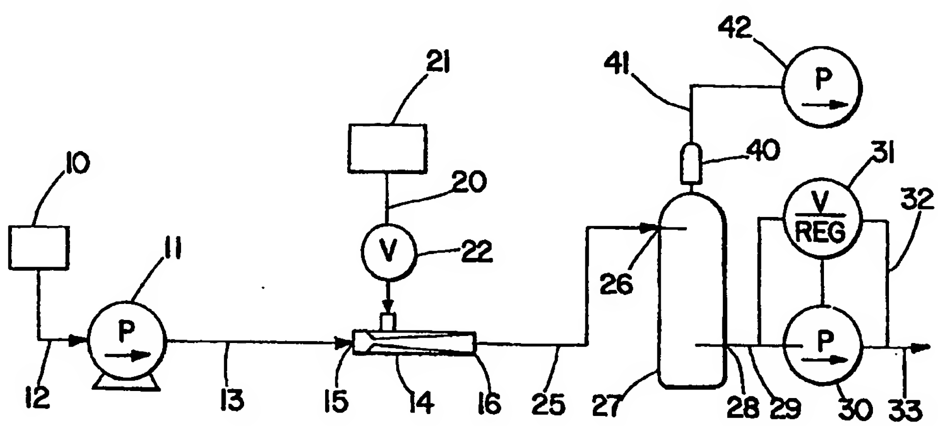
(54) Title: STRIPPING OF CONTAMINANTS FROM WATER



(57) Abstract

A process for stripping dissolved volatile contaminants from a liquid stream. The process utilizes a gas-inducing mixer-injector (14) having a throat section, with an injector port entering the throat section, the mixer-injector (14) creating a reduced pressure in the throat section so that the mixer-injector draws a stripping gas from a gas supply (21) into a stream flowing through the mixer-injector (14). The process also passes the stream from the mixer-injector (14) to a centrifugal degassing separator (27), for centrifugally separating the stripping gas from the liquid stream while maintaining the system extending from the throat of the injector to a gas outlet port and a drain port of the separator at sub-atmospheric pressure.

STRIPPING OF CONTAMINANTS FROM WATER

Specification

Field of the Invention

Removal of volatilizable contaminants from liquids such as water by means of a stripping injected gas such as air.

Background of the Invention

Water used for domestic, agricultural, and industrial use is increasingly becoming contaminated with objectionable substances. Their hazards include health risks, damage to water transmission systems and their components, damage to processing equipment, and fouling of products, crops, cropland, and industrial sites.

Because this contamination has become so severe and pervasive, it is not surprising that many efforts have been made toward remediation. Remediation in this context means removal of volatilizable compounds that are dissolved in liquid such as water to be treated, or that are dissolved in water used to extract the contaminants from soil.

There are numerous physical and chemical processes for this purpose, such as reverse osmosis and chemical treatment. However these are mostly useful for relatively small applications, and are very capital intensive in waterwork applications where the flow rate of water to be treated is very high. Further, these processes frequently involve very costly chemical reagents and high energy costs.

Other remediation pathways have been employed, especially for high rate of flow applications. Their objective is to transfer the contaminant from water into a gas, usually air. The contaminant is encouraged to leave its solution in the water and enter the gas phase as a gas, crossing the interface between the water and the gas phase as it does so. The gas with the contaminant in it is conveyed away, and the concentration of contaminant in the water is reduced.

The effectiveness of such systems is greatly impacted by the total amount of surface area of interface between the water

and the air. Common expedients to increase this surface area are found in counterflow towers, in which water flows downwardly while a current of air flows upwardly, making contact with the surface of the water. Increasing the interface area is commonly accomplished by filling the tower with a packing such as rings or plates to spread out the water for contact by the current of air.

Such equipment tends to be large, costly, and excessively consumptive of energy. It is large because the tower must accommodate bulky packing to provide sufficient interface area. It is excessively consumptive of energy because air must be passed in large amounts over the interface surface in order to keep the concentration of contaminant in the air low enough to encourage passage of the contaminant from solution into the air.

Because remediation does not produce income (except to the suppliers of the equipment), its cost, the cost of the real estate area it occupies, and the energy it consumes are subject to close and reluctant scrutiny.

Another known remediation pathway is to spray the water in the form of droplets from the top of a tower. As the droplets fall they encounter an upward counterflow of air. The interface is now on the surface of drops instead of on a sheet of water. At least theoretically the total area on the drops can be much larger than the total area provided in packed towers of similarly sized installations.

Both of these well-known systems face irreducible limits on the total surface area of their interfaces. In towers there can be only so much packing while still allowing contiguous space for sufficient air to pass through them. In spray towers there is a physical limitation on the density and size of the droplets if they are to remain discrete and separated so as to be contactible by the air. Excessive reduction of droplet size soon renders the droplet flow subject to entrainment in the air stream.

The foregoing examples illustrate the irreducible lower limits on the size of the equipment, mainly because of the

inherent requirement for space to accommodate a given amount of interface and to provide space between them for air flow that does not entrain the drops. The situation is either not improved or is worsened if the system is operated at a sub-atmospheric pressure.

Henry's law indicates that the solubility of a volatile compound in water decreases along with a decrease in system pressure. It follows that transfer from water across an interface into air is favored by a reduction in pressure. While the rate of transfer across the interface between the water and the air will be the same for the interface in any system at the same pressure with identical concentrations in the water and in the air, the above physical constraints are an ultimate limitation on the unit performance of the equipment at any pressure and temperature.

It is an object of this invention to overcome these limitations and to provide a process and process equipment which cost less to purchase and operate, while producing improved removal of the contaminant in equipment of considerably reduced size and footprint. Further, it is adaptable to a wider range of flow rates and operating pressures.

For example, a conventional counterflow tower which utilizes a downwardly flowing spray of water may require a 13 feet diameter tower, 19 feet high and about 25 hp for its operation. As an example of its effectiveness, about 85% of tetrachloroethylene (TCE) or carbon dioxide present in the water will be removed. Their Henry's constants are about equal. The cost of such an installation tends to be about US$210,000.00.

In contrast, an installation according to this invention requires a height of only about 7 feet (2.1 m)for a separation chamber about 12 inches (30 cm) in diameter for the same flow rate of water, consuming only about 8 hp. This system will remove about the same amount of the same contaminant. The cost of this installation tends to be about US$65,000.00. It is much smaller and less expensive to operate.

The superiority of results and costs of the installation and operation are evident and surprising.

Brief Description of the Invention

A system according to this invention in effect reverses the interface between the water and the gas. In the existing art the water is formed with an outer boundary (interface) externally contacted by or surrounded by the gas. This interface is where the contaminant can leave the water. Its area is limited to the total surface area of the exposed surfaces of sheets of water or the total surfaces of a group of practically-sized droplets of water. In either case, the contaminant must travel through the water in the droplets or sheets of water so as to reach the interface where it can be transferred to the air.

These conventional arrangements involve the problem that only gases which finally reach and pass through the interface can be vented. There is no assistance for the contaminant while in the water to reach the interface. The entire process relates to the migration of the released small amounts of contaminant to reach an equilibrium as indicated by Henry's law.

According to this invention a myriad of micro-bubbles of air is injected into a water stream flowing through a cavitating mixer-injector. The total surface area of the interfaces formed by these bubbles is very much greater than attainable by conventional processes. And because the bubbles can be thoroughly and vigorously mixed into the water stream, the path length of a contaminant molecule through the water to the nearest interface is greatly reduced. There are as many paths as there are bubbles, and the space between them is minimized. The mechanics of the transfer are importantly improved.

In addition, and of critical importance, is the operation of this entire system at sub-atmospheric pressure, thereby reducing the solubility of the contaminant in the water. The gas phase in the bubbles will contain an increased concentration of the contaminant for this reason, and the contaminant is

trapped in the bubble so it will not be re-dissolved in the water while at the reduced pressure.

Once this transfer of contaminant to the gas phase is accomplished and the contaminant is trapped, it is necessary to separate the gas and the contaminant it contains from the water. Conventional practice has been simply to vent the air from a tower or other separator at atmospheric pressure. However, this means that the contaminant will remain in the water in the concentration corresponding to atmospheric pressure.

According to this invention, the water stream containing the bubbles is fed to a centrifugal de-gassing separator which by spinning the water physically causes the bubbles to move toward the center, assuring their movement and passage through additional water which was previously between bubbles, thereby further increasing the rate of removal of gases. This leaves a spinning body of water substantially free of the bubbles.

Further according to this invention, the entire system, including the de-gassing separator, is operated at a sub-atmospheric pressure so the contaminant will not re-dissolve in the water. The gas phase is drawn from the separator by a vacuum pump so the separator and its gas and liquid contents remain under sub-atmospheric pressure. As a consequence of all of the foregoing, an importantly-increased removal of the contaminant is attained, because the remaining concentration of the contaminant in the water is that which corresponds to the reduced pressure as indicated by Henry's law.

The above and other features of this invention will be fully understood from the following detailed description and the accompanying drawings, in which:

<u>Brief Description of the Drawings</u>

Fig. 1 is a system diagram showing the presently preferred embodiment of the invention;

Fig. 2 is an axial cross-section of an injector useful in this invention;

Fig. 3 is a cross section taken at line 3-3 in Fig. 2;

Fig. 4 is an axial cross section of a degassing separator useful in this invention;

Fig. 5 is a cross-section taken at line 5-5 in Fig. 4, and

Fig. 6 is a cross-section taken at line 6-6 in Fig. 4.

Detailed Description of the Invention

The operative events necessary for this invention occur in a closed system maintained entirely at a sub-atmospheric pressure. While the treated liquid and the separated gases will eventually emerge into the atmosphere, the liquid and gases to be separated will be maintained at a sub-atmospheric pressure until after they are separated and are separately released from the system.

The preferred embodiment of the invention is shown in Fig. 1 where the entire main stream of liquid (water) is passed through both an injector and a centrifugal degassing separator.

A liquid supply 10 may be such as a well, pond, reservoir or main supply which supplies water for treatment. Water is disclosed as an example of liquids which can be usefully treated. Whenever water is described, it is to be understood that it exemplifies any other liquid to be treated. Booster pump 11 is a booster or supply pump to assure that the downstream system is supplied with liquid at the necessary rate of flow to sustain the system's demands. Booster pump 11 may be unnecessary if the characteristics of the water supply are such as to supply adequate water at the correct rate of flow.

Conduit 12 conveys liquid to pump 11. Conduit 13 conveys liquid from the source to a mixer injector 14. Mixer injector 14 is shown in full detail in Fig. 4. It includes an inlet port 15, an outlet port 16, and an injector port 17. A conduit 20 conveys gases from a gas supply 21 (which may be the atmosphere or a source of gas under pressure) to injector port 17 at a rate controlled in part by valve 22.

In this invention, the gas will usually be air, although it could, instead, be any other suitable gas useful for the

intended purpose. Whenever air is described, it will be understood that it is exemplary of any other useful gas.

A conduit 25 conveys water from outlet port 16 to an inlet port 26 of a centrifugal de-gassing separator 27. The de-gassing separator has a liquid outlet port 28 which discharges through conduit 29 to a booster pump 30 which will draw water from the system at a rate which maintains a desired sub-atmospheric pressure in the upstream system.

A pressure regulator valve 31 is plumbed into a by-pass loop 32 between conduit 29 and outlet conduit 33. The purpose of the regulator valve is to return water to the upstream side of the vacuum pump so as to maintain just the desired sub-atmospheric pressure in the system. Should the system pressure rise above the desired level, valve 31 will close the loop. Should the pressure decrease excessively it will open so as to admit water under downstream (atmospheric) pressure to raise the system pressure to its desired value. Booster pump 30 is preferably a centrifugal type.

Should the use of a regulator valve and by-pass loop be objectionable, then booster pump 30 may instead be a variable rate type, whose pumping rate may be adjusted to maintain the desired sub-atmospheric pressure, perhaps with a variable frequency drive slaved to a pressure/vacuum sensor in the system.

Outlet conduit 33 discharges to a point of use (not shown). The point of use may be such as a pump, a pond, a pressurized water distribution system, or any other place where suitably treated water is desired for use or for storage.

A de-gasser relief valve 40 is fitted to the top of the separator. It is sensitive to the presence of gas, and is provided with a sensor such as float 41 (Fig. 4) which indicates that there is gas to be removed, and the valve will open. Should water appear at that level, the valve will close so that only gas can leave the separator through valve 40. Of course it is necessary to expel the gas against atmospheric pressure,

because merely opening the valve without a downstream control would admit air to the separator and raise the pressure.

For this purpose, a vacuum pump 42 is connected to conduit 41 that leads from the top of the separator. It may conveniently be a vane-type or a gear-type pump. When gas is to be removed from the separator, pump 42 will operate, removing the gas by pumping it against the atmosphere, and aiding booster pump 30 in maintaining the sub-atmospheric pressure in the system.

Should the contaminants not be suitable for discharge into the atmosphere, gas from pump 42 will be sent to a suitable storage or destruction facility. For example if the contaminant is ozone, it will be sent to an ozone destructor.

The mixer-injector used in this invention is a cavitating type which draws a vacuum when water flows through its throat at a sufficient velocity. This is a distinctly different device from flow measuring venturi-type devices, in which only a reduced pressure is developed in the throat to be compared with another pressure. The objective of the mixer injector used in this invention is to draw a fluid--either gas or liquid--into a flowing stream in proportion to the mass flow through its throat and mix it into the main stream.

Injectors useful in this invention are shown in Mazzei U.S. Patent No. 4,123,800. This patent is incorporated herein by reference in its entirety for its showing of the construction of a suitable injector.

Mixer-injector 14 is shown in full detail in Fig. 2. It includes an inlet section 51, and between section 51 and exit port 16, a tapered gradually decreasing constricting section 53, a generally cylindrical throat section 54, and a tapered gradually increasing enlarging section 55. Injector port 17 enters the throat section downstream from the constricting section, preferably very close to the intersection 56 of the constricting section and the throat section. This placement next to the generally frusto-conical constricting section results in a tendency of the stream to "overshoot" the injector

port, creating a very low, sub-atmospheric pressure at the injector port, and a tendency for the injected gas and the water to mix violently. The injector port enters the throat in a group of openings, or in a peripheral groove 60 as shown in Fig. 3.

The "system" which is maintained at sub-atmospheric pressure extends from the throat section 54 of the mixer injector to pumps 30 and 42. Water and gas in this system between these locations will be at the pressure defined by the pumps.

Although any mixer injector can be used which draws a vacuum, optimum mixer injectors are shown in the Mazzei patent and in the drawings in this application. These are sold by Mazzei Injector Corporation, 500 Rooster Drive, Bakersfield, California 93307.

While any degassing separator may be used which can operate to provide centrifugal separation, an optimal device is shown in Mazzei's U.S. Patent No. 5,338,341, issued August 16, 1994, which is incorporated herein by reference in its entirety for its showing of the construction and operation of such a separator. It is also shown in Figs. 4-6 herein. Degassing separators of this type are available from Mazzei Injector Corporation, 500 Rooster Drive, Bakersfield, California 93307.

As best shown in Fig. 4, a centrifugal degassing separator 27 includes a case 66 having an inner separator chamber 67 with a cylindrical wall 69. A group of tangentially-directed nozzles 68 open into chamber 67 near its upper end so as to produce a whirling stream flowing downwardly along cylindrical wall 69 toward a drain port 70 at the lower end of the case.

A peripheral supply chamber 71 surrounds an extension 72 of wall 69 which receives water from port 26. Water flows from chamber 71 through the nozzles.

A gas separator tube 75 extends axially downward into chamber 67. It is cylindrical and hollow, and has a plurality of slots 76 through it. Gas outlet port 77 exits at the upper

end of the case. Gas outlet valve 40 connects to gas outlet port 77.

In operation, the centrifugal force of the whirling stream causes gas bubbles to migrate toward the center, whereby to pass through the slots and rise in the separator tube toward the outlet.

It will be observed that both the mixer-injector and the degassing separator are always under sub-atmospheric pressure while the system is operating. The system is filled with water or whatever liquid is being treated, along with the undissolved gases in the liquid, and along with the gases injected by the mixer-injector. Until after the treatment is completed there is no exposure of the liquid in the system to the atmosphere.

Depending on system parameters, conduit 25 may or may not be provided, and the effluent from the mixer-injector could be injected directly into the de-gassing separator. However, it frequently will be desirable to provide more residence time for the gas to transfer into the bubbles before removing the gas from the water and a length of conduit, or even a tank can be provided for that purpose. Generally a very high percentage of the contaminant which ultimately could be removed is in fact removed while the gas is still in enlarging section 55.

The size and proportions of the elements of the system will be selected according to system performance parameters, such as rate of flow of liquid required, and the nature and concentration of the contaminants.

A broadly useful group of operating pressure conditions is as follows (the measurements given in Kpa are all absolute measurements--the psig measurements are gauge pressures):

Conduit 13:	20 psig (240 KPa)
Conduit 25:	10 in Hg (25.4 cm Hg or 33.8 KPa)
Conduit 28:	15 in Hg (38.1 cm Hg or 50.7 KPa)
Conduit 33:	20 psig (240 KPa)
Conduit 41:	20 in Hg (50.8 cm Hg or 67.6 KPa)

At these pressures, the reduction of concentration of contaminant gas will be importantly reduced. The previously-

given examples of removal of TCE carbon and dioxide is such an example.

The term "volatilizable" is used herein to mean a contaminant which is dissolved in the liquid, but which can be drawn as a gas into the gas phase. Other examples are other VOC's (volatile organic compounds) such as tetrachloroethylene and benzene ethyl toluene xylene (BETEX). Other gases are such as radon and oxygen.

This invention is not to be limited by the embodiments shown in the drawings and described in the description, which are given by way of example and not of limitation, but only in accordance with the scope of the appended claims.

CLAIMS

1. The process for stripping dissolved volatile contaminants from a liquid stream, comprising the following steps in the order recited:

utilizing a gas-inducing mixer-injector having an inlet port, an outlet port, a tapered constricting section, a substantially cylindrical throat section, an enlarging section, and an outlet port in that order, and an injector port entering said throat section, said sections being so proportioned and arranged as to create a reduced pressure in said throat when said liquid stream flows through from inlet port to outlet port, flowing said stream through said injector, said mixer-injector drawing a stripping gas into said stream through said injector port;

passing the stream from said mixer-injector to a centrifugal degassing separator, whereby the stream provided to the degassing separator includes said liquid and bubbles of said stripping gas, said bubbles including contaminant;

said de-gassing separator having a drain port, an inner separator chamber with a cylindrical wall and nozzle means proportioned and arranged so as to discharge said stream tangentially along said cylindrical wall to create a swirling centrifugal flow from the nozzles toward the drain port, a perforated gas separator tube extending centrally in said chamber to receive stripping gas that is centrifugally separated from the liquid, and a gas outlet port opening into said separator tube;

withdrawing separated gas from said separator tube through said gas outlet port, and liquid from said drain port, while maintaining the system extending from the throat of the injector to the gas outlet port and the drain port of the separator at sub-atmospheric pressure.

2. A process according to claim 1 in which a booster pump having an inlet and an outlet drains liquid from said drain port and thereby causes said sub-atmospheric pressure, and in which a by-pass loop including a pressure regulator valve interconnects said booster pump inlet and booster pump outlet to maintain a desired sub-atmospheric pressure.

3. The process according to claim 2 in which a booster pump supplies said liquid to the inlet port of the mixer-injector at a rate sufficient to supply the liquid required to flow through the system at the selected sub-atmospheric pressure.

4. The process according to claim 1 in which a booster pump drains liquid from said drain port at a rate to maintain a desired sub-atmospheric pressure in said system, said booster pump being a variable rate pump.

5. The process according to any one of the preceding claims in which a vacuum pump draws gas from said gas outlet port.

6. A system for stripping dissolved volatile contaminants from an incoming liquid stream from a source of said liquid to produce an outgoing liquid stream with a reduced concentration of said contaminant, said system comprising:

a cavitating type mixer-injector comprising a body, said body having a passage therethrough with an inlet port, an outlet port, a tapered constricting section, a generally cylindrical throat section, and a tapered enlarging section in that order between said inlet port and said outlet port, an injector port through said body opening into said throat section, said constricting section and throat section being so proportioned as to form a local region of reduced pressure in said throat;

said injector port being adapted to receive stripping gas from a source of stripping gas;

a centrifugal de-gasser separator having an inlet port in fluid communication with the outlet port of said injector, a drain port to release liquid from which stripping gas and some contaminant has been separated by said separator, and a gas outlet port to release gas that has been separated from the stream by said separator, said separator comprising a case having an inlet port and forming an inner separator chamber with a cylindrical wall having a linear axis, a nozzle in said inlet port directing flow of liquid in a tangential path on said cylindrical wall whereby to produce a whirling stream flowing toward said drain port, a gas separator tube extending axially and centrally in said chamber from said gas outlet port, said separator tube being hollow and having a plurality of perforations therethrough along its length, there being a substantial annular spacing between said separator tube and said cylindrical wall;

a gas outlet valve in said gas outlet port; and

said system being adapted for operation at sub-atmospheric pressures and being closed between the throat section of the mixer-injector and the drain port and gas outlet port of the separator except at the injector port of said injector.

7. A system according to claim 6 in which a vacuum pump is connected to said gas outlet valve to expel gas from said de-gassing separator.

8. A system according to claim 5, 6 or 7 in which a booster pump is plumbed to said drain port to pump liquid from the separator chamber and maintain a sub-atmospheric pressure in the system, and in which a regulator valve connects the inlet and outlet ports of said booster pump to maintain a selected sub-atmospheric pressure.

9. A system according to claim 6 or 7 in which a booster pump is plumbed to said drain port to pump liquid from the separator chamber and maintain a sub-atmospheric pressure in the system, said booster pump being a variable rate pump.

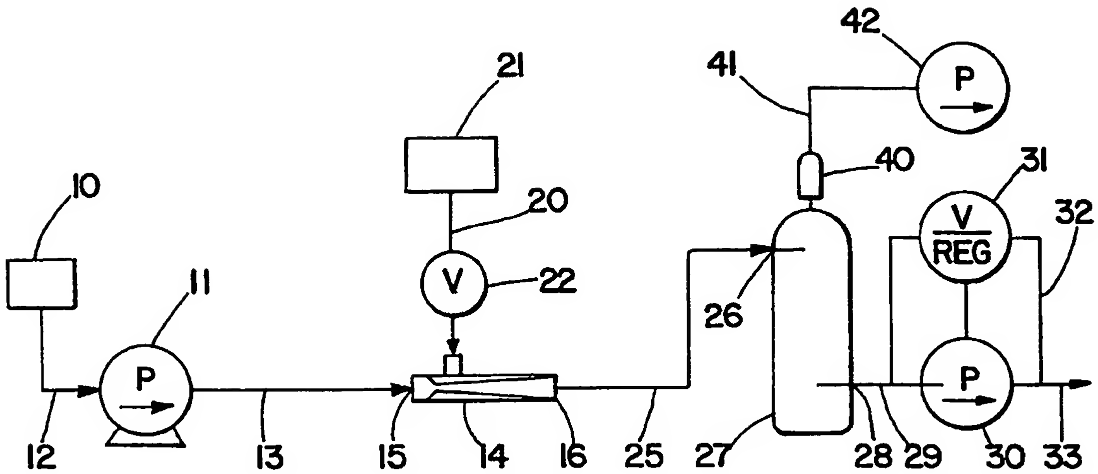


Fig. 1

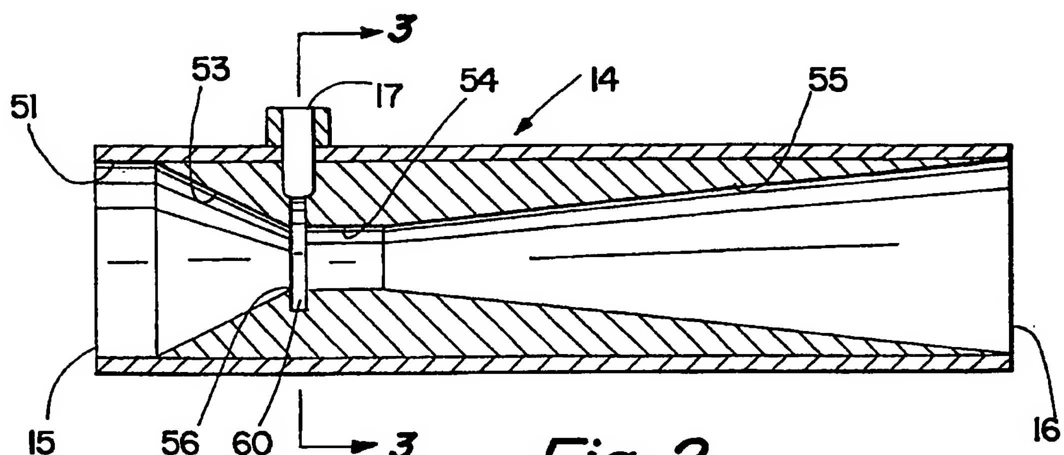
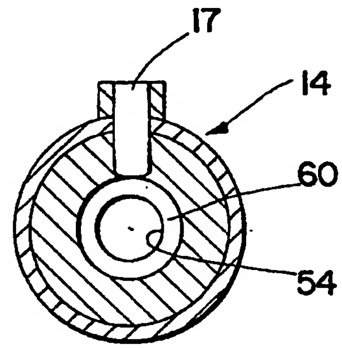


Fig. 2

Fig. 3



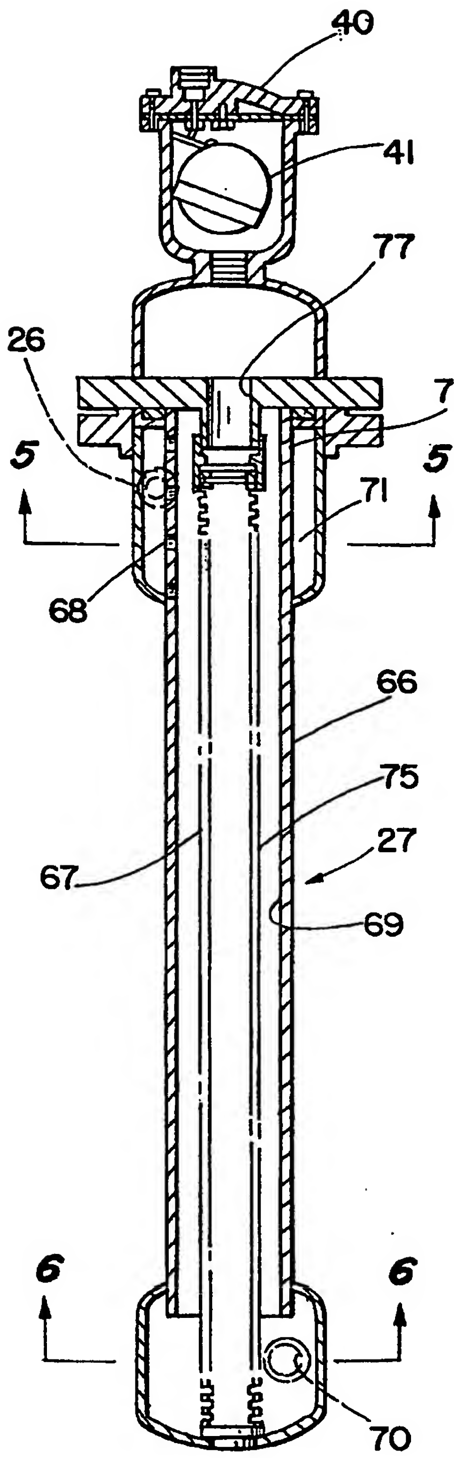


Fig. 4

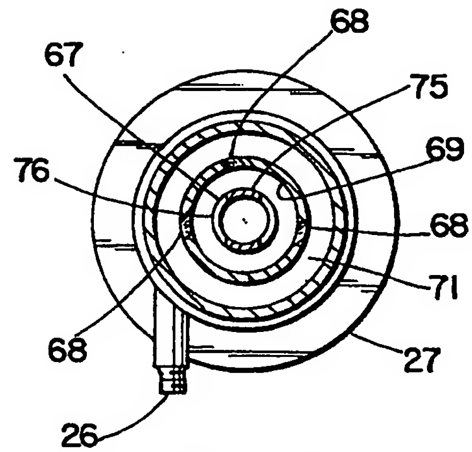


Fig. 5

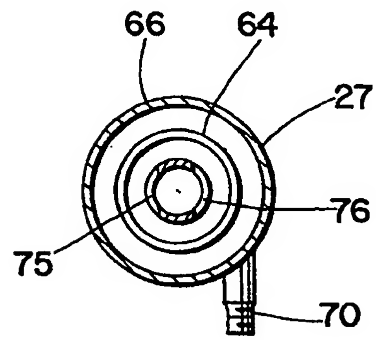


Fig. 6

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US99/05635

A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) :B01D 17/035, 19/00, 45/12; BO1F 5/04
US CL :Please See Extra Sheet.
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 55/468; 95/254, 261, 263; 96/202, 208, 209; 210/702, 718, 738, 750, 787, 788, 512.1; 366/163.2

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5,674,312 A (MAZZEI) 07 October 1997, abstract and col. 5, line 27 to col. 6, line 15.	1 and 6
Y	US 5,338,341 A (MAZZEI et al.) 16 August 1994, abstract.	1 and 6
Y	US 4,123,800 A (MAZZEI) 31 October 1978, abstact.	1 and 6
A	US 5,202,032 A (SHOEMAKER) 13 April 1993, entire document.	1-9

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
28 MAY 1999	14 JUN 1999

Name and mailing address of the ISA/US	Authorized officer
Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231 Facsimile No. (703) 305-3230	DAVID A. REIFSNYDER Telephone No. (703) 308-0661

Form PCT/ISA/210 (second sheet)(July 1992)★

A. CLASSIFICATION OF SUBJECT MATTER:
US CL :

55/468; 95/254, 261, 263; 96/202, 208, 209; 210/702, 718, 738, 750, 787, 788, 512.1; 366/163.2